Bridge Design for Earthquake Fault Crossings: Synthesis of Design Issues and Strategies

RESULTS: The Fault-Rupture Response Analysis (FR-RSA) procedure is shown to predict bridge displacement responses that are close enough to the results from the "exact" Response History Analysis (RHA) for representative curved bridges crossing fault ruptures. The other approximate analysis approach, Fault-Rupture Linear Static Analysis (FR-LSA) procedure, is found to provide reasonable results for three-span bridge but overly conservative results for four-span bridge. For the three- and four-span bridges considered in this study, the quasi-static response (which is caused by ground displacement offset only) alone is found not to be adequate in estimating the total bridge response.

Background

In response to the observed earthquake-induced bridge damages and the absence of practical analysis methods for bridge crossing fault rupture zones, a previous study funded by Caltrans developed two simplified procedures, namely, the Fault Rupture-Response Spectrum Analysis (FR-RSA) and Fault Rupture-Linear Static Analysis (FR-LSA) procedures as alternatives of the onerous Response History Analysis (RHA) procedure. However, prior validation work of these procedures was limited to ideal straight ordinary bridges. Since a significant number of actual bridges in California have some features different from the bridges used in the prior validation work, there is an urgent research need to further evaluate the adequacy of the simplified analysis procedures in the context of representative actual bridges, particularly curved bridges. In addition, a critical knowledge gap exists in implementing the approximate procedures in practical design. Extensive analytical work was conducted in this investigation to address these issues.

What We Did

This research first selected two curved bridges – a three-span and a four-span – representative of typical California construction. The selected bridges were assumed to cross strike-slip fault ruptures. Numerical models of the selected bridges were developed using OpenSees. Then, adequacy of FR-RSA and FR-LSA was examined through result comparisons with the most rigorous RHA procedure. A set of ten ground motion records, which include a relative fault offset of 100 cm were used in this investigation. The ground offset was determined to place bridge bents well into the inelastic range while not so large as to completely dominate the contribution of the dynamic response. The bridge displacement response quantities extracted for validation purpose include: abutment longitudinal displacement, abutment transverse displacement, and resultant bent drift. Other parameters considered in the numerical models and varied in the analysis include: abutment longitudinal stiffness, bridge-to-fault angles, and fault locations.

Selected Three-span Bridge

Selected Four-span Bridge

**Illustration of Bridge-to-Fault Angle**
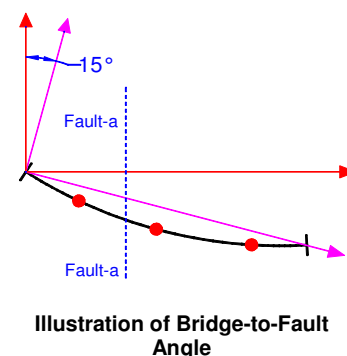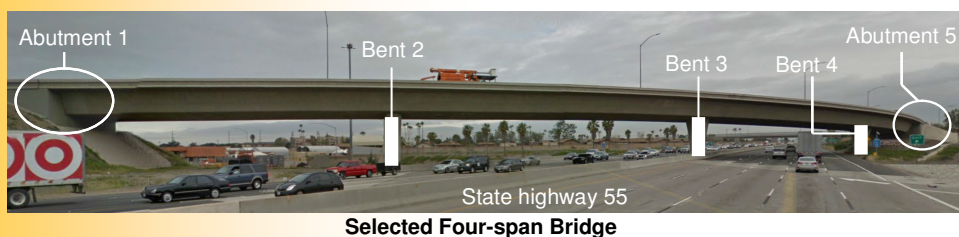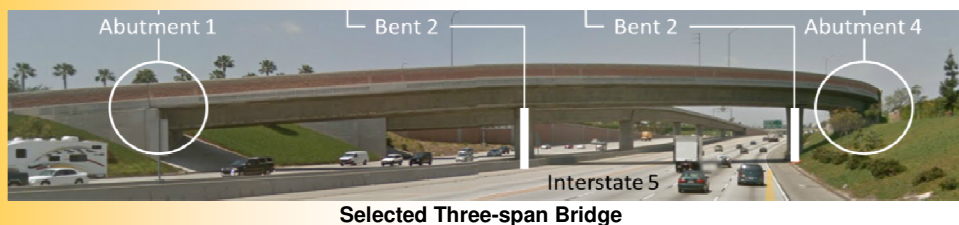
Implementation and Validation

An important component of this investigation focuses on implementation and validation of the FR-RSA procedure in an existing bridge analysis and design platform that is more convenient for bridge engineers. For this purpose, the research team assisted Computers & Structures, Inc. in implementing the FR-RSA procedure on CSiBridge™. Using the three-span bridge as an example, the research team developed a step-by-step procedure for implementing the FR-RSA procedure in CSiBridge™ and assessed the adequacy of this implementation.
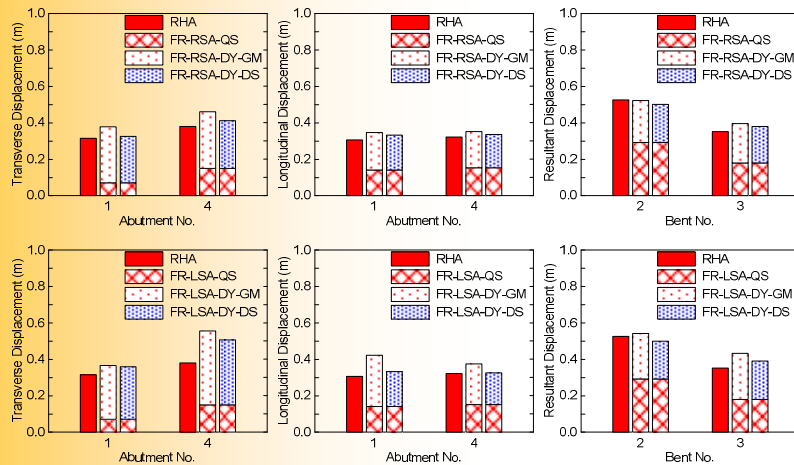
Typical OpenSees Result Comparisons: RHA vs FR-RSA and RHA vs. FR-LSA
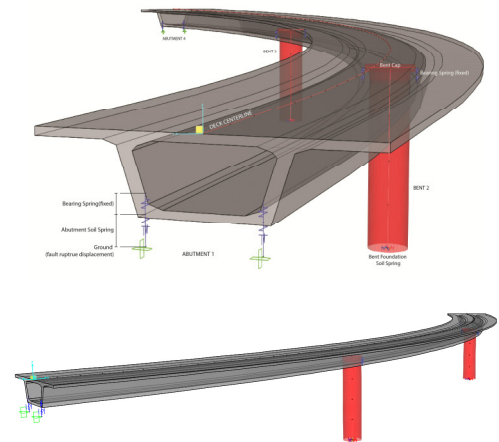
Model developed in CSiBridge™

Research Results

Based on the numerical simulations conducted in this research, the key results are summarized below:

- Analysis results from both three-span and four-span bridges demonstrate that the quasi-static response alone (which is caused by ground displacement offset only) is inadequate in estimating the bridge response.
- FR-RSA consistently provides reasonable demand estimates in all considered cases accounting for different numbers of bents, longitudinal abutment stiffness values, fault locations, and fault-to-bridge angles.
- FR-LSA provides reasonable results for the three-span bridge; but predicts overly conservative demand estimates for the four-span bridge. Therefore, it is suggested that the FR-LSA procedure should be used with caution in bridges with more than three spans.
- FR-RSA implemented on CSiBridge™ provides adequate predictions for bridge responses and can be used in future practice.

Recommendations

Based on the results from this investigation, it is found that FR-RSA can be used as an alternative to the nonlinear RHA with multiple support excitation, and is recommended for future practical application. Moreover, it is recommended to further examine the adequacy of the approximate analysis procedures for bridges crossing other types of earthquake fault ruptures, identify the critical/vulnerable components, and develop the corresponding design implication for bridge crossing fault ruptures.

Reference

Goel, R., Qu, B., Rodriguez, O., Tures, J., "Bridge Design for Earthquake Fault Crossings: Synthesis of Design Issues and Strategies", Final Report, January 2013, 113 pp.

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